

FIG. 1

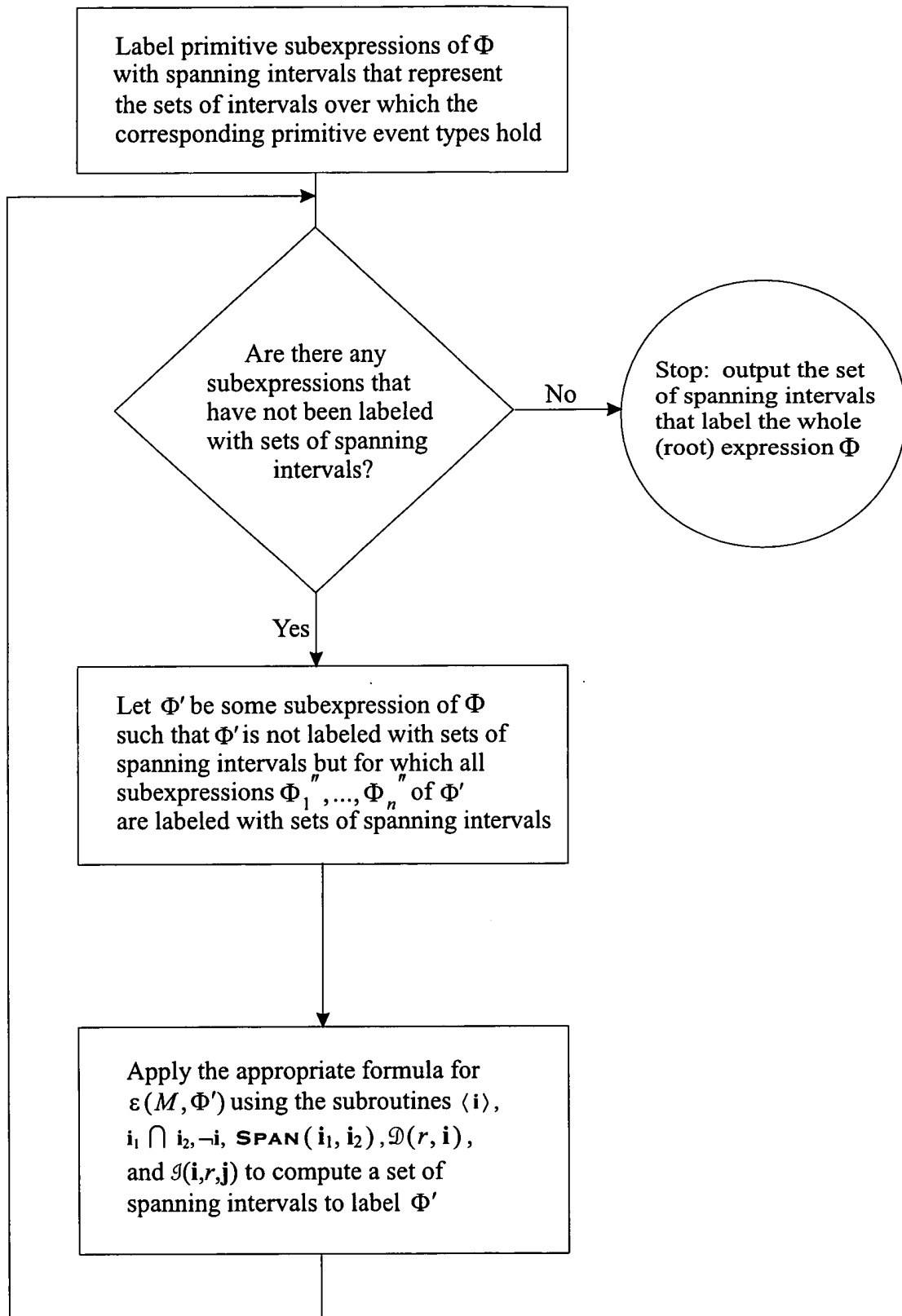


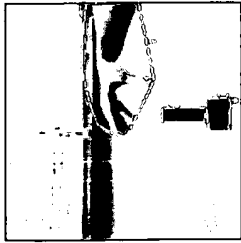
FIG. 2

$$\begin{array}{lcl}
 x = y & \triangleq & \overline{x = y} \\
 \text{SUPPORTED}(x) & \triangleq & \overline{\neg \text{GROUNDED}(x)} \\
 \text{RIGIDLY ATTACHED}(x, y) & \triangleq & (\exists r) \text{RIGID}(x, y, r) \\
 \text{SUPPORTS}(x, y) & \triangleq & \left(\overline{\begin{array}{l} \neg \text{GROUNDED}(y) \wedge \\ \neg \text{STABLE}(P \setminus \{x\}, M \cup \{\text{GROUNDED}(z) | \neg \text{RIGIDLY ATTACHED}^*(z, y)\}) \end{array}} \right) \\
 \text{CONTACTS}(x, y) & \triangleq & \overline{\text{TOUCHES}(x, y) \wedge x \bowtie y} \\
 \text{ATTACHED}(x, y) & \triangleq & \overline{(\exists r) \text{RIGID}(x, y, r) \vee \text{REVOLUTE}(x, y, r)}
 \end{array}$$

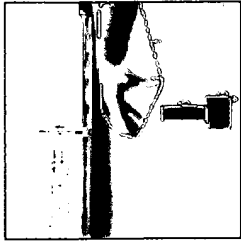
FIG. 3

$$\begin{aligned}
 \text{PICKUP}(x, y, z) &\triangleq \left(\begin{array}{l} \neg \Diamond x = y \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{SUPPORTED}(y) \wedge \neg \Diamond \text{ATTACHED}(x, z) \wedge \\ \left\{ \begin{array}{l} \neg \Diamond \text{ATTACHED}(x, y) \wedge \neg \Diamond \text{SUPPORTS}(x, y) \wedge \\ \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right\} ; \\ \left\{ \begin{array}{l} \text{ATTACHED}(x, y) \vee \text{ATTACHED}(y, z) ; \\ \text{ATTACHED}(x, y) \wedge \text{SUPPORTS}(x, y) \wedge \\ \neg \Diamond \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right\} \end{array} \right) \\
 \\
 \text{PUTDOWN}(x, y, z) &\triangleq \left(\begin{array}{l} \neg \Diamond x = y \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{SUPPORTED}(y) \wedge \neg \Diamond \text{ATTACHED}(x, z) \wedge \\ \left\{ \begin{array}{l} \text{ATTACHED}(x, y) \wedge \text{SUPPORTS}(x, y) \wedge \\ \neg \Diamond \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right\} ; \\ \left\{ \begin{array}{l} \text{ATTACHED}(x, y) \vee \text{ATTACHED}(y, z) ; \\ \neg \Diamond \text{ATTACHED}(x, y) \wedge \neg \Diamond \text{SUPPORTS}(x, y) \wedge \\ \text{SUPPORTS}(z, y) \wedge \\ \neg \Diamond \text{SUPPORTED}(x) \wedge \neg \Diamond \text{ATTACHED}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(y, x) \wedge \neg \Diamond \text{SUPPORTS}(y, z) \wedge \\ \neg \Diamond \text{SUPPORTS}(x, z) \wedge \neg \Diamond \text{SUPPORTS}(z, x) \end{array} \right\} \end{array} \right) \\
 \\
 \text{STACK}(w, x, y, z) &\triangleq \left[\begin{array}{l} \neg \Diamond z = w \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{PUTDOWN}(w, x, y) \wedge \text{SUPPORTS}(z, y) \wedge \neg \text{ATTACHED}(z, y) \end{array} \right] \\
 \text{UNSTACK}(w, x, y, z) &\triangleq \left[\begin{array}{l} \neg \Diamond z = w \wedge \neg \Diamond z = x \wedge \neg \Diamond z = y \wedge \\ \text{PICKUP}(w, x, y) \wedge \text{SUPPORTS}(z, y) \wedge \neg \text{ATTACHED}(z, y) \end{array} \right] \\
 \text{MOVE}(w, x, y, z) &\triangleq \neg \Diamond y = z \wedge [\text{PICKUP}(w, x, y); \text{PUTDOWN}(w, x, z)] \\
 \text{ASSEMBLE}(w, x, y, z) &\triangleq \text{PUTDOWN}(w, y, z) \wedge_{\{<\}} \text{STACK}(w, x, y, z) \\
 \text{DISASSEMBLE}(w, x, y, z) &\triangleq \text{UNSTACK}(w, x, y, z) \wedge_{\{<\}} \text{PICKUP}(x, y, z)
 \end{aligned}$$

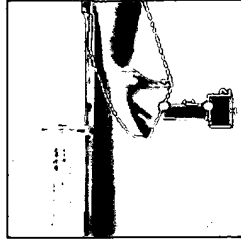
FIG. 4



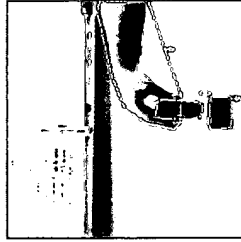
frame 0



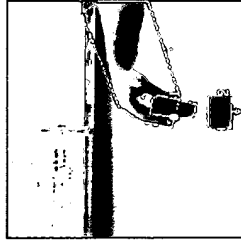
frame 1



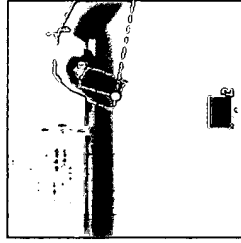
frame 2



frame 13

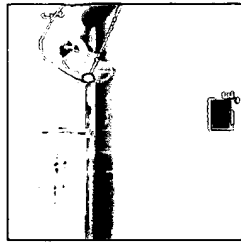


frame 14

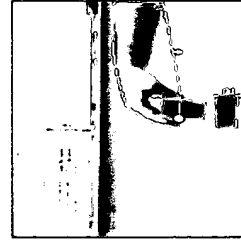


frame 20

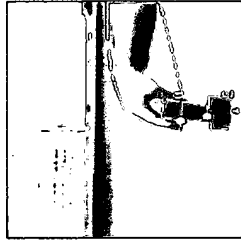
FIG. 5A



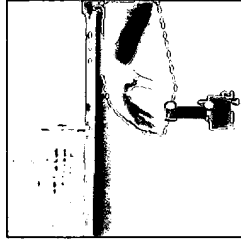
frame 1



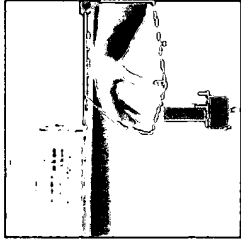
frame 13



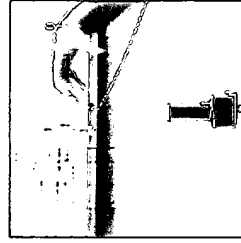
frame 14



frame 22



frame 23



frame 27

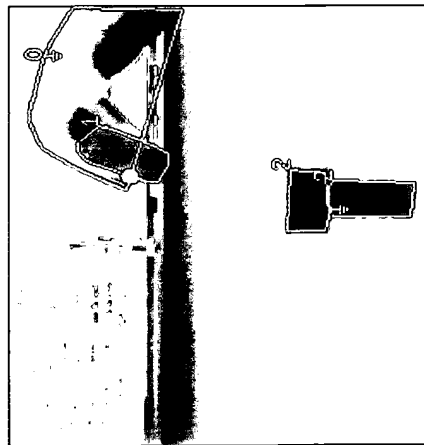
FIG. 5B

```
(PICK-UP MOVING RED GREEN)@([[0,1],[14,22]])
(SUPPORTED? RED)@([[0:22]])
(SUPPORTED? MOVING)@([[1:13]], [[24:26]])
(SUPPORTS? RED MOVING)@([[1:13]], [[24:26]])
(SUPPORTS? MOVING RED)@([[13:22]])
(SUPPORTS? GREEN RED)@([[0:14]])
(SUPPORTS? GREEN MOVING)@([[1:13]])
(CONTACTS? RED GREEN)@([[0:2]], [[6:14]])
(ATTACHED? RED MOVING)@([[1:26]])
(ATTACHED? RED GREEN)@([[1:6]])
```

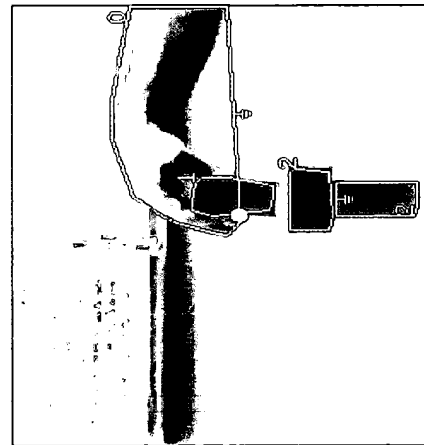
FIG. 6A

```
(PUT-DOWN MOVING RED GREEN)@([[0,14],[23,32]])
(SUPPORTED? MOVING)@([[14:23]])
(SUPPORTED? RED)@([[0:32]])
(SUPPORTS? MOVING RED)@([[0:14]])
(SUPPORTS? RED MOVING)@([[14:23]])
(SUPPORTS? GREEN MOVING)@([[14:23]])
(SUPPORTS? GREEN RED)@([[14:32]])
(CONTACTS? RED GREEN)@([[22:32]])
(ATTACHED? MOVING RED)@([[0:23]])
(ATTACHED? RED GREEN)@([[14:22]])
```

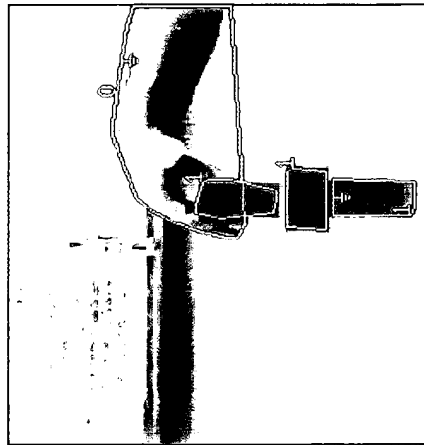
FIG. 6B



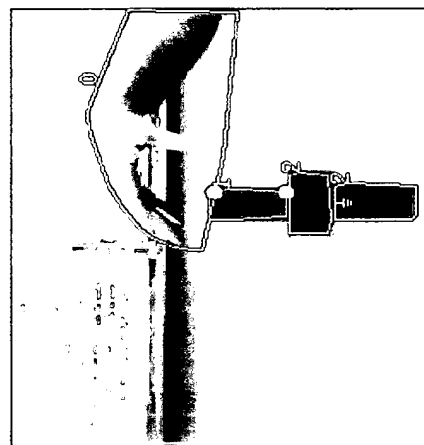
frame 3



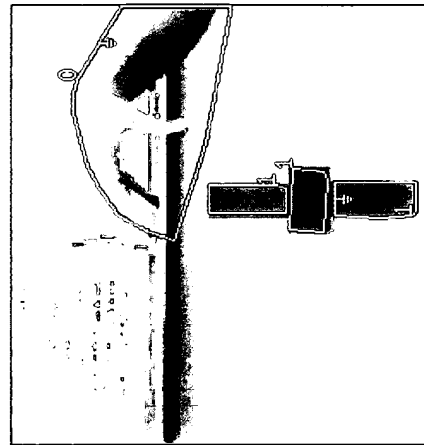
frame 11



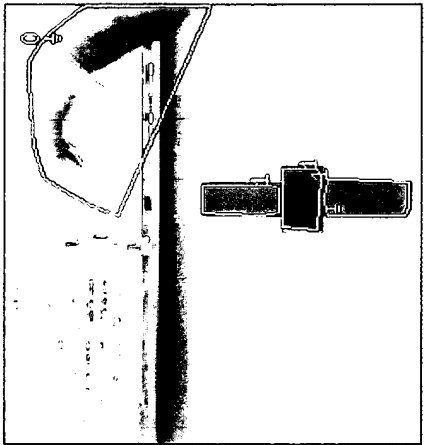
frame 12



frame 23



frame 24



frame 26

FIG. 7A

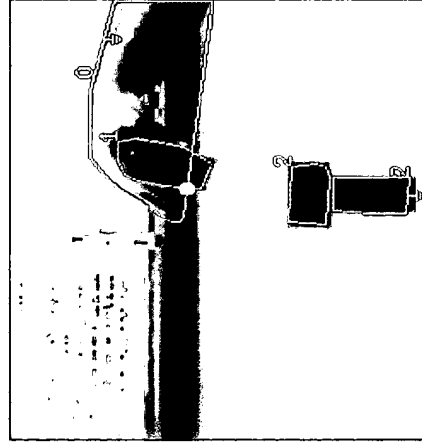
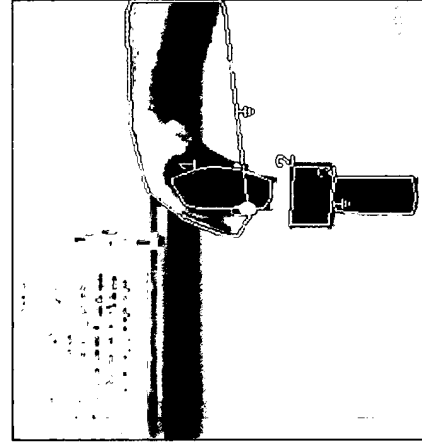
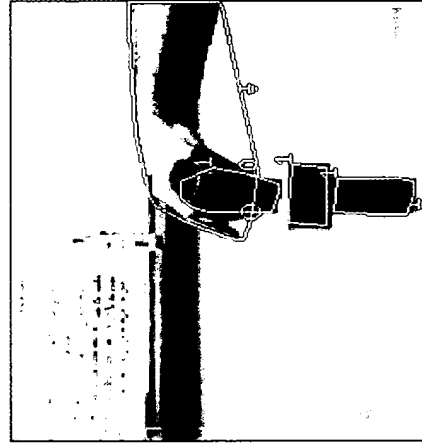
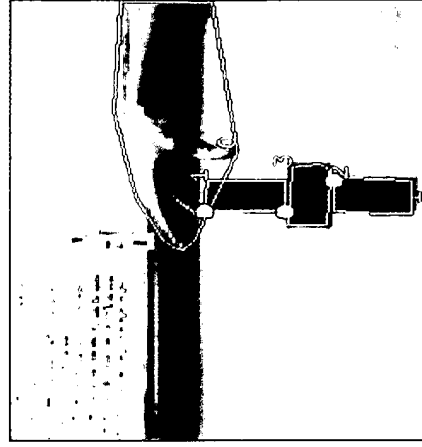
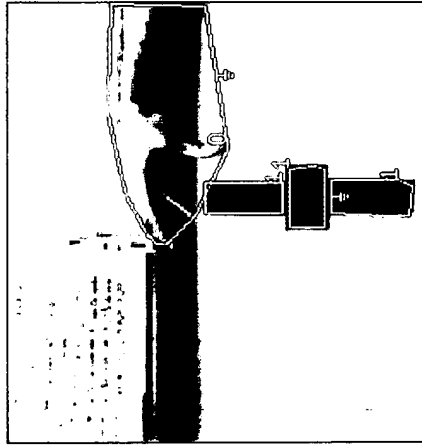
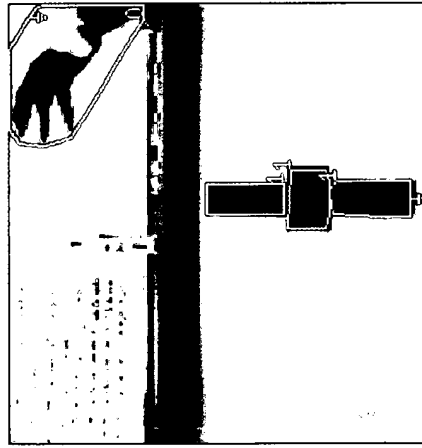
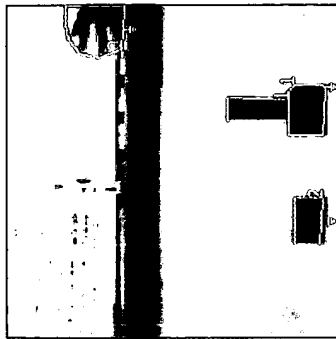
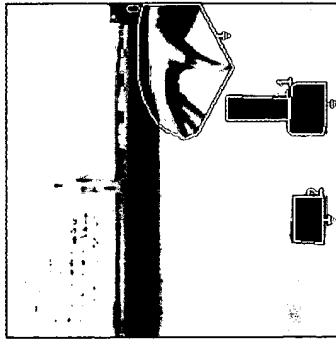


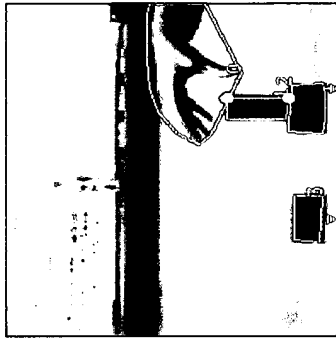
FIG. 7B



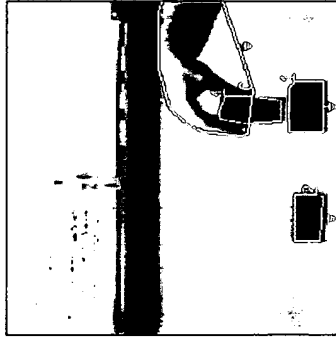
frame 0



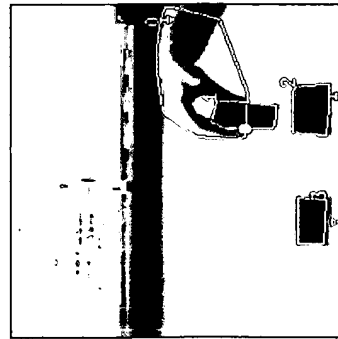
frame 8



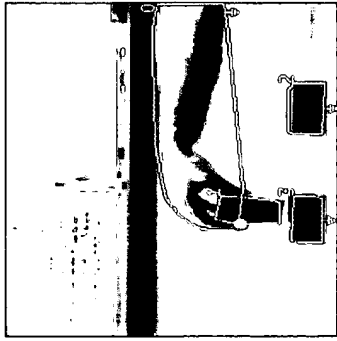
frame 9



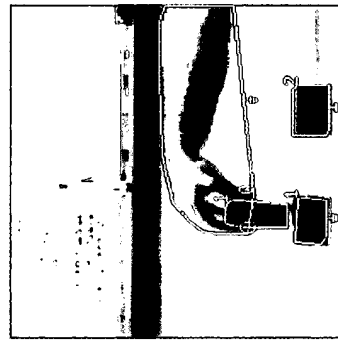
frame 16



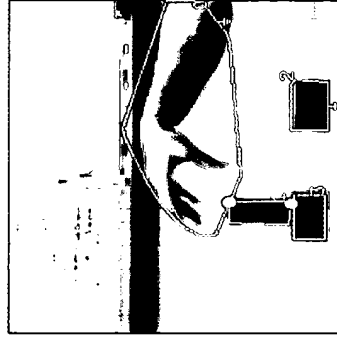
frame 17



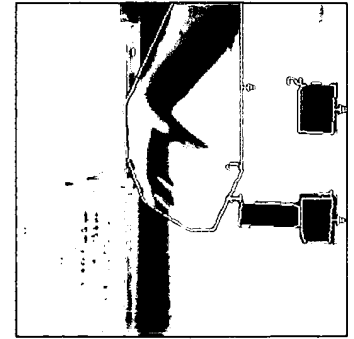
frame 33



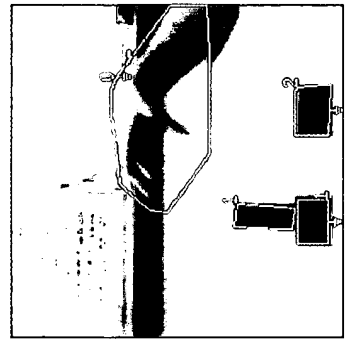
frame 34



frame 45

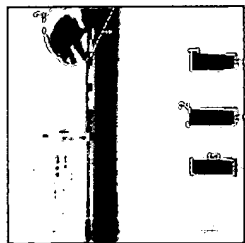


frame 46

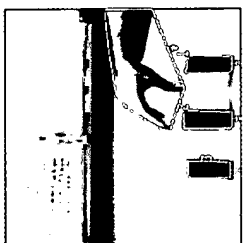


frame 47

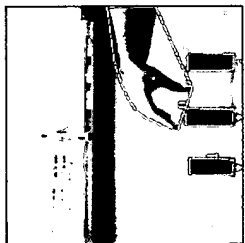
FIG. 7C



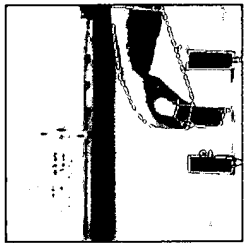
frame 0



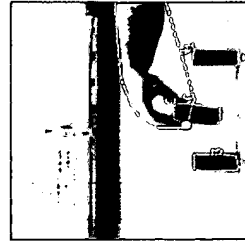
frame 9



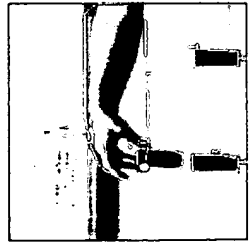
frame 10



frame 17



frame 18



frame 32



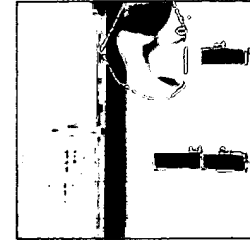
frame 33



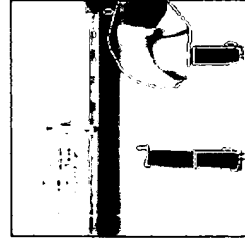
frame 40



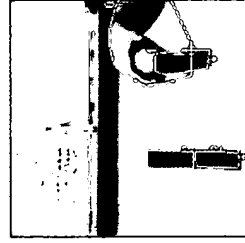
frame 41



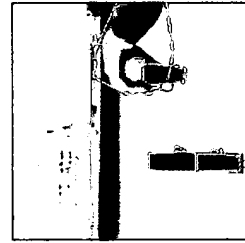
frame 46



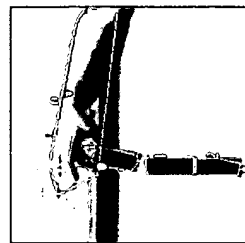
frame 47



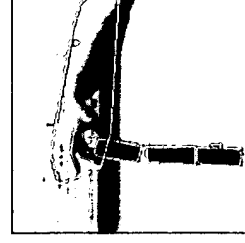
frame 56



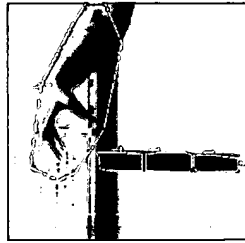
Frame 57



frame 67

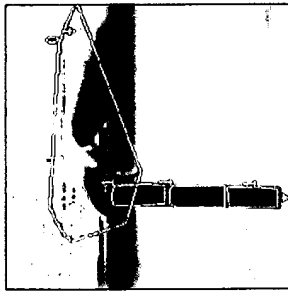


frame 68

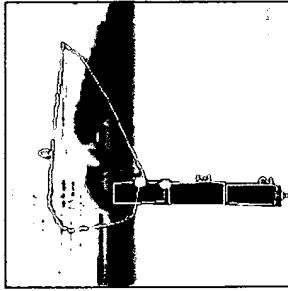


frame 80

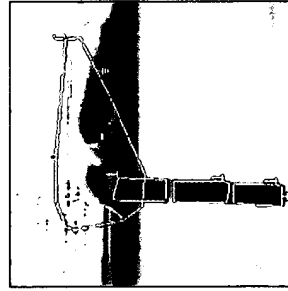
FIG. 7D



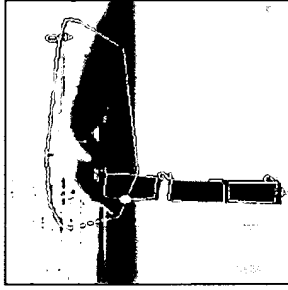
frame 18



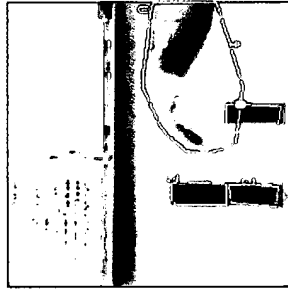
frame 19



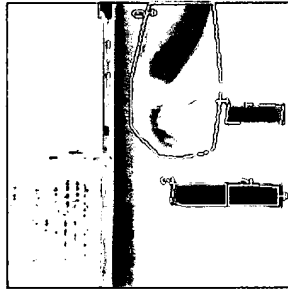
frame 22



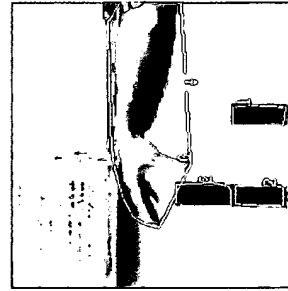
frame 23



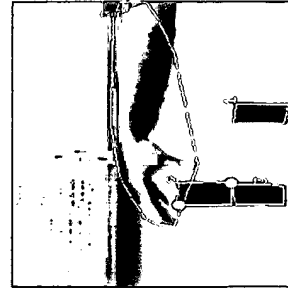
frame 49



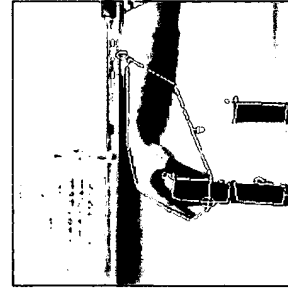
frame 50



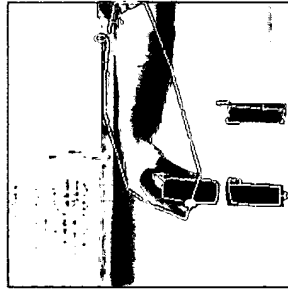
frame 56



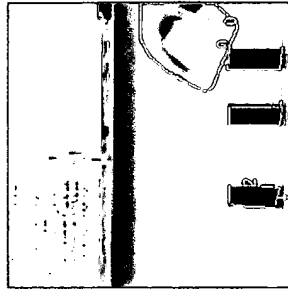
frame 57



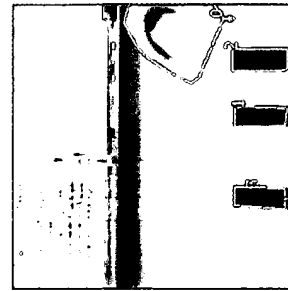
frame 62



frame 63



frame 87



frame 88

```
(PUT-DOWN MOVING RED BLUE)*([0,12],[24,30])
(STACK MOVING RED BLUE GREEN)*([0,12],[24,30])
```

```
(SUPPORTED? MOVING)*([13:24])
(SUPPORTED? RED)*([0:30])
(SUPPORTED? BLUE)*([0:30])
(SUPPORTS? MOVING RED)*([0:12])
(SUPPORTS? RED MOVING)*([13:24])
(SUPPORTS? RED BLUE)*([19:20],[21:22])
(SUPPORTS? GREEN MOVING)*([19:20],[21:22])
(SUPPORTS? GREEN RED)*([19:20],[21:22])
(SUPPORTS? GREEN BLUE)*([0:30])
(SUPPORTS? BLUE MOVING)*([13:24])
(SUPPORTS? BLUE RED)*([12:30])
(CONTACTS? RED BLUE)*([12:19],[20:21],[22:30])
(CONTACTS? GREEN BLUE)*([0:30])
(ATTACHED? MOVING RED)*([0:24])
(ATTACHED? RED BLUE)*([19:20],[21:22])
```

FIG. 8A

```
(PICK-UP MOVING RED BLUE)*([0,11],[25,33])
(UNSTACK MOVING RED BLUE GREEN)*([0,11],[25,33])
```

```
(SUPPORTED? MOVING)*([11:23])
(SUPPORTED? RED)*([0:36])
(SUPPORTED? BLUE)*([0:36])
(SUPPORTS? MOVING RED)*([23:36])
(SUPPORTS? RED MOVING)*([11:23])
(SUPPORTS? RED BLUE)*([13:14])
(SUPPORTS? GREEN MOVING)*([13:14])
(SUPPORTS? GREEN RED)*([13:14])
(SUPPORTS? GREEN BLUE)*([0:36])
(SUPPORTS? BLUE MOVING)*([11:23])
(SUPPORTS? BLUE RED)*([0:25])
(CONTACTS? MOVING RED)*([34:36])
(CONTACTS? RED BLUE)*([0:13],[14:24])
(CONTACTS? GREEN BLUE)*([0:13],[14:36])
(ATTACHED? MOVING RED)*([11:33])
(ATTACHED? RED BLUE)*([13:14])
(ATTACHED? GREEN BLUE)*([13:14])
```

FIG. 8B

```
(PICK-UP MOVING RED GREEN)*([0,9],[17,46])
(PUT-DOWN MOVING RED BLUE)*([17,35],[46,52])
(MOVE MOVING RED GREEN BLUE)*([0,9],[46,52])
```

```
(SUPPORTED? MOVING)*([9:15])
(SUPPORTED? RED)*([0:52])
(SUPPORTED? BLUE)*([35:46])
(SUPPORTS? MOVING RED)*([17:46])
(SUPPORTS? MOVING BLUE)*([35:46])
(SUPPORTS? RED MOVING)*([9:15])
(SUPPORTS? RED BLUE)*([35:46])
(SUPPORTS? GREEN MOVING)*([9:15])
(SUPPORTS? GREEN RED)*([0:17])
(SUPPORTS? BLUE RED)*([46:52])
(CONTACTS? RED GREEN)*([0:17])
(CONTACTS? RED BLUE)*([46:52])
(ATTACHED? MOVING RED)*([9:46])
(ATTACHED? RED BLUE)*([35:46])
```

FIG. 8C

```
(PUT-DOWN MOVING RED GREEN)*([57,68],[68,87])
(PUT-DOWN MOVING GREEN BLUE)*([18,35],[41,47])
(STACK MOVING RED GREEN BLUE)*([57,68],[68,87])
(ASSEMBLE MOVING RED GREEN BLUE)*([18,35],[68,87])
```

```
(SUPPORTED? MOVING)*([10:18],[47:57])
(SUPPORTED? RED)*([57:87])
(SUPPORTED? GREEN)*([11:87])
(SUPPORTED? BLUE)*([35:41])
(SUPPORTS? MOVING RED)*([57:68])
(SUPPORTS? MOVING GREEN)*([11:41])
(SUPPORTS? MOVING BLUE)*([35:41])
(SUPPORTS? RED MOVING)*([10:18],[47:57])
(SUPPORTS? RED GREEN)*([11:16])
(SUPPORTS? GREEN RED)*([68:87])
(SUPPORTS? GREEN BLUE)*([35:41])
(SUPPORTS? BLUE GREEN)*([41:87])
(CONTACTS? RED GREEN)*([68:87])
(CONTACTS? GREEN BLUE)*([41:87])
(ATTACHED? MOVING RED)*([11:16],[49:68])
(ATTACHED? MOVING GREEN)*([11:41])
(ATTACHED? GREEN BLUE)*([35:41])
```

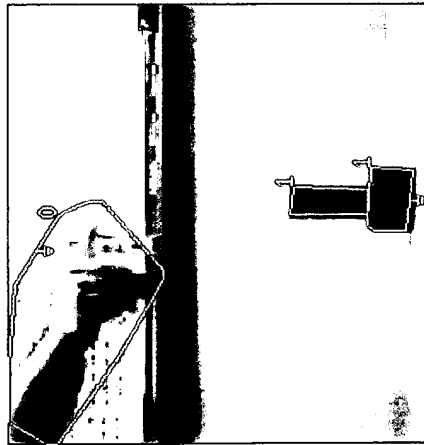
FIG. 8D

```
(PICK-UP MOVING RED GREEN)*([0,19],[23,50])
(PICK-UP MOVING GREEN BLUE)*([22,58],[62,87])
(UNSTACK MOVING RED GREEN BLUE)*([0,19],[23,50])
(DISASSEMBLE MOVING RED GREEN BLUE)*([0,19],[62,87])
```

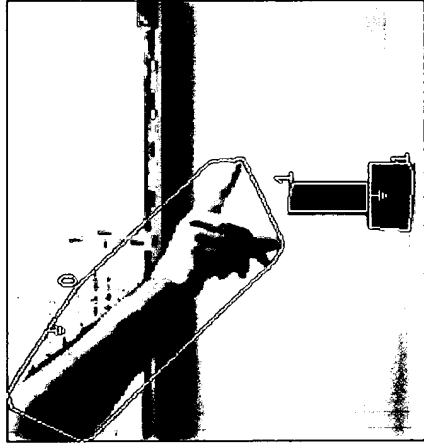
```
(SUPPORTED? MOVING)*([19:22])
(SUPPORTED? RED)*([0:50])
(SUPPORTED? GREEN)*([0:87])
(SUPPORTED? BLUE)*([58:62])
(SUPPORTS? MOVING RED)*([23:50])
(SUPPORTS? MOVING GREEN)*([58:87])
(SUPPORTS? MOVING BLUE)*([58:62])
(SUPPORTS? RED MOVING)*([19:22])
(SUPPORTS? GREEN MOVING)*([19:22])
(SUPPORTS? GREEN RED)*([0:23])
(SUPPORTS? GREEN BLUE)*([58:62])
(SUPPORTS? BLUE GREEN)*([0:58])
(CONTACTS? RED GREEN)*([0:23])
(CONTACTS? GREEN BLUE)*([0:58])
(ATTACHED? MOVING RED)*([19:50])
(ATTACHED? MOVING GREEN)*([58:87])
(ATTACHED? GREEN BLUE)*([58:62])
```

FIG. 8E

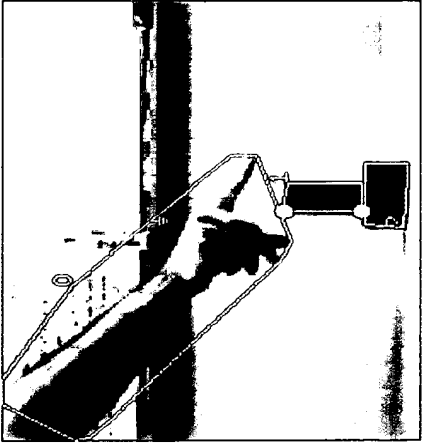
FIG. 9A



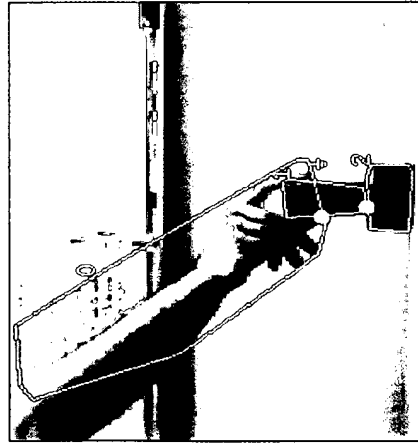
frame 5



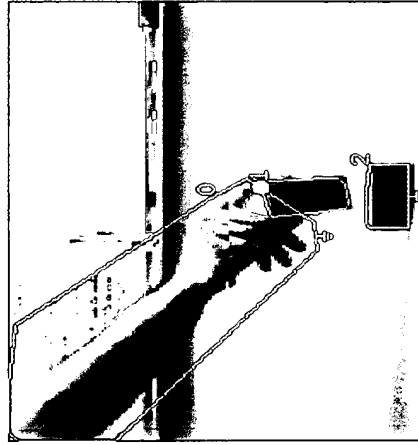
frame 10



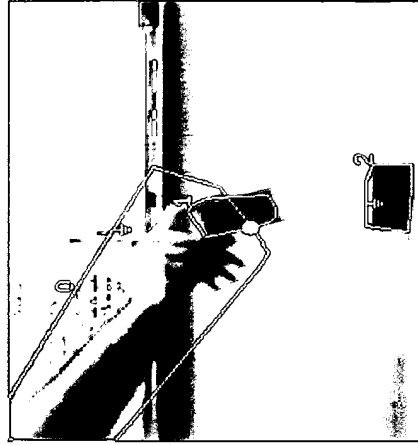
frame 11



frame 17

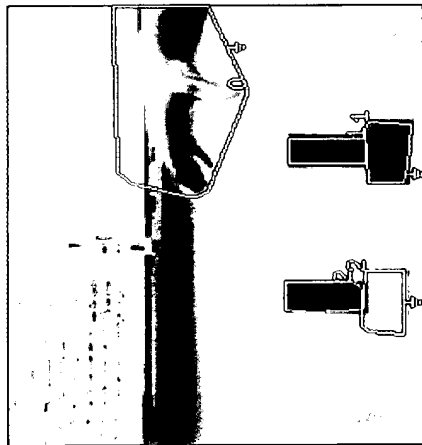


frame 18

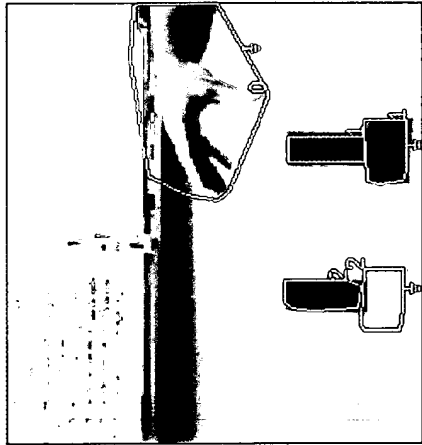


frame 22

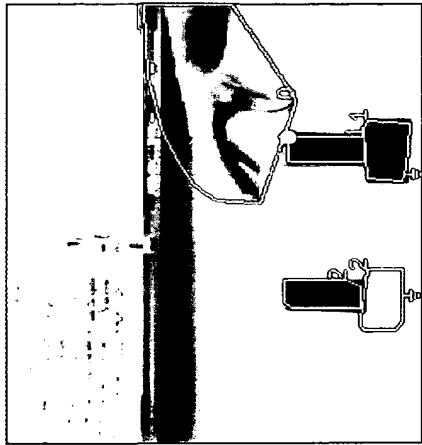
FIG. 9A



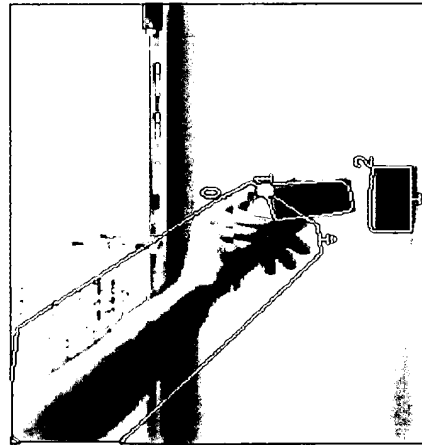
frame 6



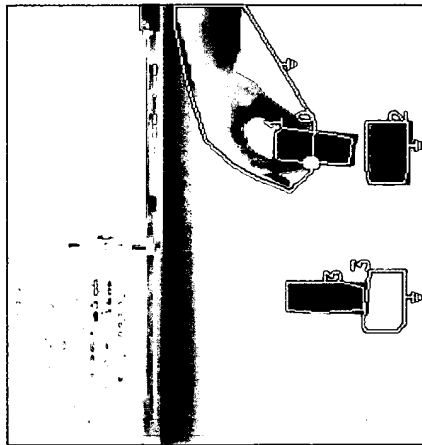
frame 7



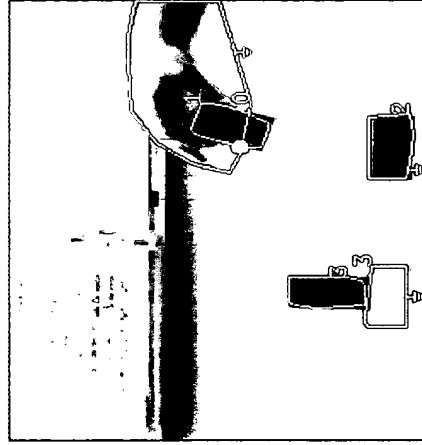
frame 8



frame 18

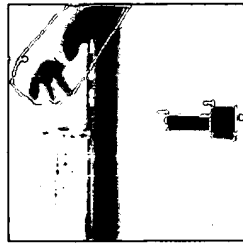


frame 19

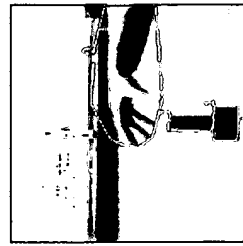


frame 24

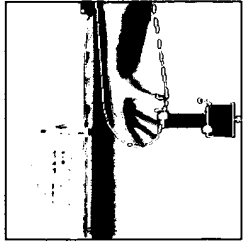
FIG. 9B



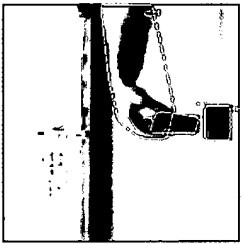
frame 4



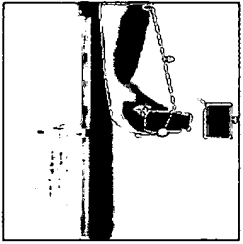
frame 8



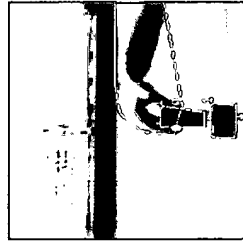
frame 9



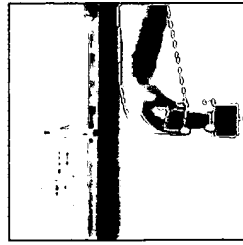
frame 18



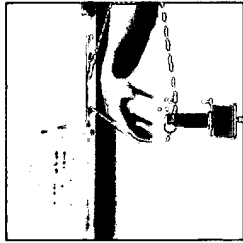
frame 19



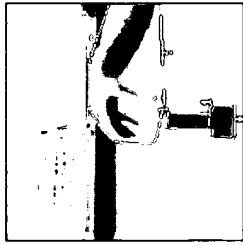
frame 44



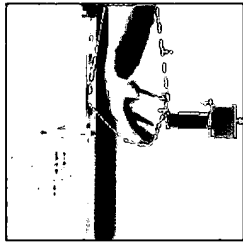
frame 45



frame 51



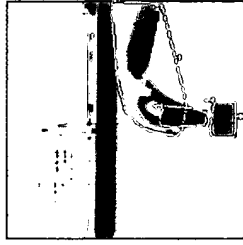
frame 52



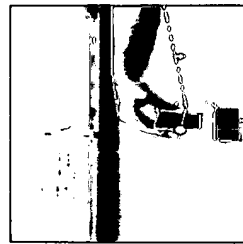
frame 69



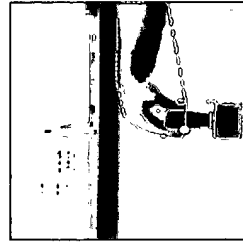
frame 70



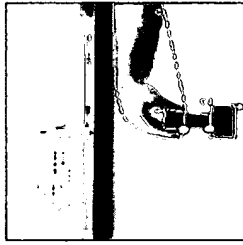
frame 77



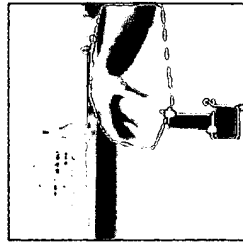
frame 78



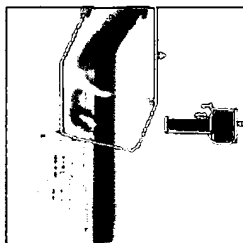
frame 102



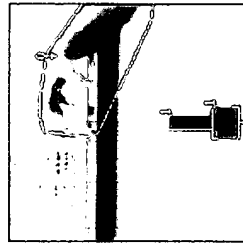
frame 103



frame 109



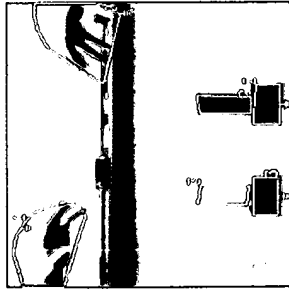
frame 110



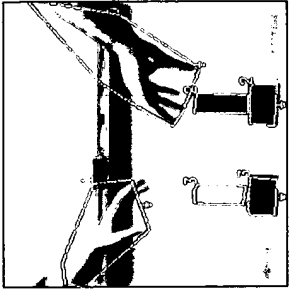
frame 111

FIG. 9C

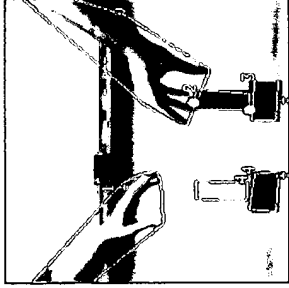
FIG. 9D



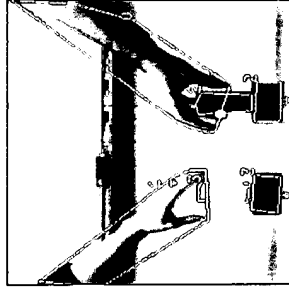
frame 0



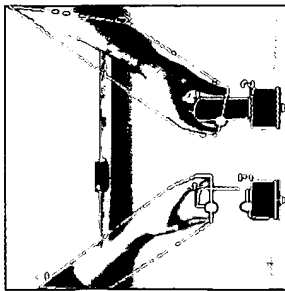
frame 5



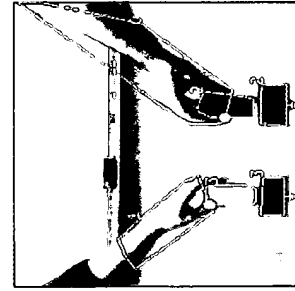
frame 6



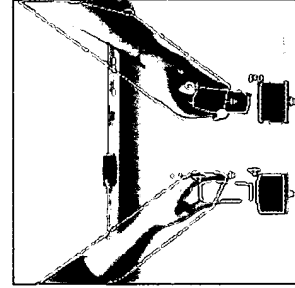
frame 10



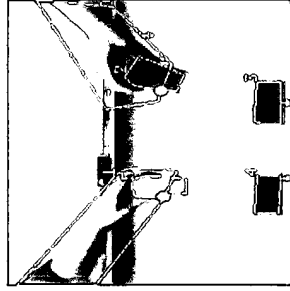
frame 11



frame 15



frame 16



frame 21

FIG. 9D


```
(PICK-UP MOVING RED GREEN)*([0,11],[18,30]))
(SUPPORTED? RED)*([0:30]))
(SUPPORTED? GREEN)*([11:18]))
(SUPPORTS? MOVING RED)*([11:30]))
(SUPPORTS? MOVING GREEN)*([11:18]))
(SUPPORTS? RED GREEN)*([11:18]))
(SUPPORTS? GREEN RED)*([0:11]))
(CONTACTS? RED GREEN)*([0:11]))
(ATTACHED? MOVING RED)*([11:30]))
(ATTACHED? RED GREEN)*([11:18]))
```

FIG. 10A

```
(PICK-UP MOVING RED GREEN)*([0,8],[19,30]))
(SUPPORTED? MOVING)*([8:19]))
(SUPPORTED? RED)*([0:30]))
(SUPPORTED? BLUE)*([0:30]))
(SUPPORTS? MOVING RED)*([19:30]))
(SUPPORTS? RED MOVING)*([8:19]))
(SUPPORTS? GREEN MOVING)*([8:19]))
(SUPPORTS? GREEN RED)*([0:19]))
(SUPPORTS? YELLOW BLUE)*([0:30]))
(CONTACTS? RED GREEN)*([0:10],[16:19]))
(CONTACTS? BLUE YELLOW)*([0:30]))
(ATTACHED? MOVING RED)*([8:30]))
(ATTACHED? RED GREEN)*([10:16]))
```

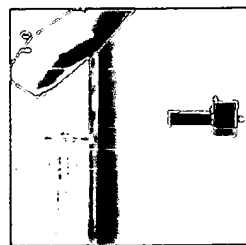
FIG. 10B

```
(PICK-UP MOVING RED GREEN)*([52,70],[78,102]), [0,9],[19,44]))
(PUT-DOWN MOVING RED GREEN)*([19,44],[62,70]), [78,102],[110,117]))
(SUPPORTED? MOVING)*([9:18]), [44:52]), [70:77]), [102:110]))
(SUPPORTED? RED)*([0:117]))
(SUPPORTS? MOVING RED)*([18:44]), [78:102]))
(SUPPORTS? RED MOVING)*([9:18]), [44:52]), [70:77]), [102:110]))
(SUPPORTS? GREEN MOVING)*([9:18]), [44:52]), [70:77]), [102:110]))
(SUPPORTS? GREEN RED)*([0:19]), [44:78]), [102:117]))
(CONTACTS? RED GREEN)*([0:9]), [13:18]), [46:70]), [106:117]))
(ATTACHED? MOVING RED)*([9:52]), [70:110]))
(ATTACHED? RED GREEN)*([9:13]), [70:76]), [104:106]))
```

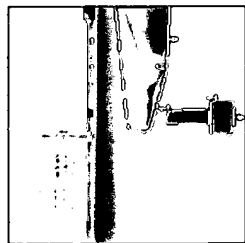
FIG. 10C

```
(PICK-UP MOVING RED GREEN)*([0,6],[16,22]))
(PICK-UP MOVING YELLOW BLUE)*([0,12],[17,22]))
(SUPPORTED? MOVING)*([6:16]))
(SUPPORTED? MOVING)*([12:15]))
(SUPPORTED? RED)*([0:22]))
(SUPPORTED? YELLOW)*([0:22]))
(SUPPORTS? MOVING RED)*([16:22]))
(SUPPORTS? MOVING YELLOW)*([17:22]))
(SUPPORTS? RED MOVING)*([6:16]))
(SUPPORTS? GREEN MOVING)*([6:16]))
(SUPPORTS? GREEN RED)*([0:16]))
(SUPPORTS? BLUE MOVING)*([12:15]))
(SUPPORTS? BLUE YELLOW)*([0:17]))
(SUPPORTS? YELLOW MOVING)*([12:15]))
(CONTACTS? RED GREEN)*([0:15]))
(CONTACTS? BLUE YELLOW)*([0:17]))
(ATTACHED? MOVING RED)*([6:22]))
(ATTACHED? MOVING YELLOW)*([12:22]))
```

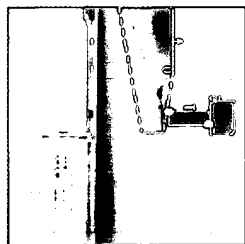
FIG. 10D



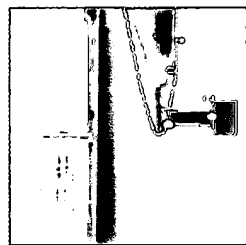
frame 0



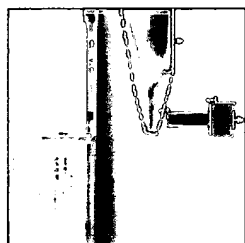
frame 6



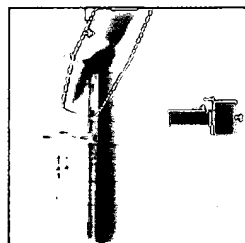
frame 7



frame 12

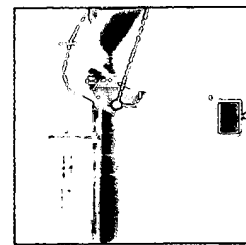


frame 13

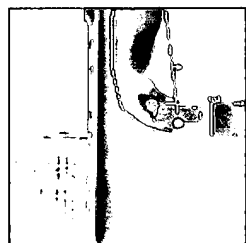


frame 18

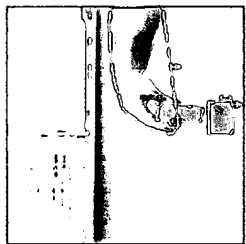
FIG. 11A



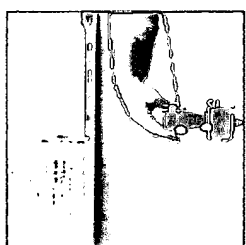
frame 4



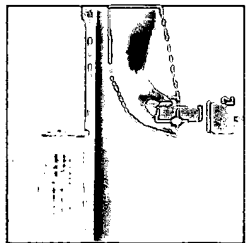
frame 11



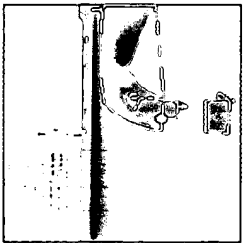
frame 12



frame 18



frame 19



frame 21

FIG. 11B

```
(SUPPORTED? RED)@([[0:25]])
(SUPPORTED? GREEN)@([[7:13]])
(SUPPORTS? MOVING RED)@([[7:13]])
(SUPPORTS? MOVING GREEN)@([[7:13]])
(SUPPORTS? RED GREEN)@([[7:13]])
(SUPPORTS? GREEN RED)@([[0:7]], [[13:25]])
(CONTACTS? RED GREEN)@([[0:7]], [[13:25]])
(ATTACHED? MOVING RED)@([[7:13]])
(ATTACHED? RED GREEN)@([[7:13]])
```

FIG. 12A

```
(SUPPORTED? RED)@([[0:19]])
(SUPPORTED? MOVING)@([[13:31]])
(SUPPORTS? RED MOVING)@([[13:31]])
(SUPPORTS? MOVING RED)@([[0:13]])
(SUPPORTS? GREEN RED)@([[12:19]])
(SUPPORTS? GREEN MOVING)@([[13:19]])
(ATTACHED? RED MOVING)@([[0:31]])
(ATTACHED? RED GREEN)@([[13:19]])
```

FIG. 12B